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Tests of Highly Loaded Skids on a Concrete Runway

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Tests of Highly Loaded Skids on a Concrete Runway

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Abstract

Skids have been used at various times for aircraft landing gear ever since the Wright Flyer appeared in the early 1900's. Typically, skids have been employed as aircraft landing gear either at low speeds or at low-bearing pressures. In this investigation, tests were conducted to examine the friction and wear characteristics of various metals sliding on a rough, grooved concrete runway. The metals represented potential materials for an overload protection skid for the Space Shuttle orbiter. This report presents data from tests of six skid specimens conducted at higher speeds and bearing pressures than those of previous tests in the open literature. Skids constructed of tungsten with embedded carbide chips exhibited the lowest wear, whereas a skid constructed of Inconel 718 exhibited high wear rates. Friction coefficients for all the skid specimens were moderate and would provide adequate stopping performance on a long runway. Because of its low wear rate, a skid constructed of tungsten with embedded carbide chips is considered to be a likely candidate for an aircraft skid or overload protection skid.

Introduction

Skids have been proposed and occasionally used as the primary landing system on aircraft on several occasions in the past. One example is the X-15 aircraft (ref. 1). The X-15 program evaluated several skid materials and found that on dry lakebeds, mean coefficients of friction above 0.3 were common and sometimes reached values of 0.6. All X-15 data were obtained at skid bearing pressures of approximately 30 psi. Reference 2 presents data from the testing of solid skids as well as wire brush skids on surfaces including concrete, asphalt, and dry lakebeds. Those tests were conducted at speeds up to 90 knots and at bearing pressures of approximately 25 psi. The tests produced friction coefficients over 0.5 in some cases.

A proposal was made to install a skid between the two tires on each main gear of the Space Shuttle orbiter to prevent overloading and failing of the remaining good tire if one tire had deflated prior to landing or had failed for any reason early in the landing rollout. The proposed skid would be required to slide on a concrete surface faster and with higher bearing pressures than any skid heretofore tested. In the case of the orbiter, the skid would have a bearing pressure of over 1100 psi and would be required to operate at speeds up to 180 knots. Operating such a skid on the orbiter makes it desirable to have a relatively low friction coefficient because simulator studies have shown that the orbiter is very difficult to control laterally if the friction coefficient on one strut exceeds 0.4. Also, a skid with low-wear characteristics is desirable to keep added weight to a minimum.

The purpose of this paper is to present results of tests conducted at the Langley Research Center to determine friction and wear characteristics of various potential materials proposed for the overload protection skid of the Space Shuttle orbiter. These tests, which were conducted at speeds up to 173 knots and at bearing pressures up to 1110 psi, were discussed previously in reference 3.

Apparatus and Procedure

Test Facility

This investigation was conducted at the Langley Aircraft Landing Dynamics Facility (ALDF) (fig. 1), which consists of a set of rails 2800 ft long on which a 108 000-lb high-speed carriage travels. The carriage, shown in figure 2, is propelled at speeds up to 220 knots using a high-pressure water jet and is arrested using a set of water turbines connected across the track by nylon tapes. An assembly referred to as the "drop carriage" (shown in figs. 2 and 3) rides on vertical rails inside the main test carriage. Test fixtures are attached to the drop carriage and are hydraulically loaded onto the runway surface during a test run. A more detailed description of the facility can be found in reference 4.

Instrumentation

A force-measurement dynamometer (fig. 3) is normally attached to the drop carriage. However, in

these tests the tire shown in figure 3 was removed and a skid test apparatus was attached to the dynamometer. Details of the force-measurement dynamometer are shown in the photograph and sketch in figure 4. The dynamometer has instrumented load cells so that ground-reaction forces can be measured. Vertical and drag loads were each measured using a set of two strain-gauged beams. Analog data from each transducer were converted to digital signals onboard the carriage by a pulse-code modulation system and were serially telemetered at 1600 frames/sec to a receiving station where the data stream was decommutated. This set of data remained in digital form and was fed into a desktop computer. The same set of data was also passed through a digital-to-analog converter and fed through a 14-channel frequency-modulated tape recorder; ultimately, the data were reproduced by a 14-channel oscillograph to give an immediate accounting of carriage and transducer performance during a run. The telemetry system is capable of providing a 200-Hz response. The digital signals transmitted from the carriage permitted a data resolution of 1 part in 256. Normally, the expected range on each channel was approximately 75 percent of the maximum, thus resulting in a resolution of the system of approximately 0.5 percent.

Data Reduction

During a run, the digital data received from the carriage are recorded by the desktop computer at a rate of 1600 samples/sec. Typically, force data are retrieved from the computer memory at a rate of 1600 samples/sec and then are mathematically filtered to 5 Hz. Raw data are then translated into engineering units by using appropriate calibration constants. In this report, raw data are not inertially corrected to extract the vibrations of the mass supported by the strain-gauged load beams. Chattering of the skid specimens with no shock absorber to smooth the loads produced over-scale values on the drag load channels, as can be seen in figure 5. The ordinate on the plot is in raw data (counts) instead of pounds. The instrumentation cannot report any behavior below zero counts. The figure shows spikes in the data with virtually no time of developed load as the spikes approach zero counts. For this reason, the over-scale values are considered to have an insignificant effect on the interpretation of drag force.

In this investigation, certain mechanical limitations caused the measured vertical loads to be less than the actual applied vertical loads. The torque produced by the generation of drag load by the skid caused some of the actual vertical load to be transferred through the torque link of the dynamometer around the measurement beam. Consequently, a calibration has been applied to all the vertical-load data presented in this report. This calibration is achieved by adding 80 percent of the measured drag load to the measured vertical load to produce an actual vertical load. The drag force is then divided by the vertical load to obtain the drag-force friction coefficients (referred to herein as "friction coefficients") presented in this report.

Hardware

These tests were conducted by using the skid test apparatus shown in figure 6. The apparatus consists of a modified test wheel axle, a laterally movable bracket, and a pivoting shoe to which various skid specimens are attached. Gussets and a thick steel plate were welded to an existing heavy-duty axle. Five sets of mounting holes (see fig. 6(b)) were arranged so that the lateral placement of the skids could be varied to provide different ground tracks on the concrete runway surface in case the runway surface was damaged from a skid test. A torque reaction arm was welded to the axle and attached to the framework of the dynamometer to keep the axle from rotating. A sketch of the torque reaction apparatus is shown in figure 7.

Six skid materials were tested, four of which are shown in figure 8. The skids shown include specimens of Inconel 718, 4340 steel, 1020 steel, and Haynes Stellite superalloy. Specimens not shown include tungsten with medium carbide chips and tungsten with coarse carbide chips.

Each 58.4-in^2 specimen was 12.625 in. long by 4.625 in. wide in a trapezoidal shape that provided a 45° upward bevel on the front edge. Specimens were mounted to the pivoting shoe at the bottom of the bracket shown in figure 6. The pivot was displaced 1.125 in. toward the rear of the center of the ground contact plane of the skid specimen. The bevel and the rearward displacement of the pivot were designed to ensure against gouging or digging into the runway.

The Inconel 718 alloy skid was solution treated and aged to Rockwell hardness RC39-40 (RC39). The AISI 4340 alloy skid was heat treated to RC52-55 (RC52). The AISI 1020 was heat treated to RC36-40 (RC40). These three skid specimens had the same material throughout the entire specimen thickness. The Stellite specimen consisted of Stellite applied to an Inconel 718 base. The thickness of the Stellite material was not known with certainty; thus, after the first test run, the assumption was made that

at least a portion of the sliding surface of the skid was worn down to and sliding on the Inconel 718 base material. For the tungsten carbide skids, the tungsten with medium or coarse carbide chips was applied to an Inconel 718 base. The tests conducted with these skids did not have enough wear to erode through the tungsten carbide surface.

A photograph of the runway surface is shown in figure 9. The test runway was a simulation of the rough runway at the Kennedy Space Center. It had an extremely rough longitudinally brushed texture with transverse grooves 0.25 in. wide by 0.25 in. deep with a 1 1/8-in. spacing.

Test Procedure

To conduct skid testing, the high-speed carriage was accelerated to the desired speed, the skid attached to the dynamometer was lowered to the concrete surface, and then the desired vertical load was applied for 100 to 400 ft of sliding distance. The load was then removed and the skid was raised from the test surface. The thickness of the skid was recorded before and after each test at the four corners of the sliding surface to determine the amount of wear for that run.

Results and Discussion

Six skid specimens were tested to determine their friction and wear characteristics at higher speeds and bearing pressures than can be found in the open literature. Table 1 presents the results of skid tests and shows speed, vertical load, bearing pressure, drag force, friction coefficient, slide distance, wear, and wear rate for each test. The pivot on the pivoting shoe of the skid apparatus was behind the geometric center of the skid specimen and caused the pressure distribution of the footprint to shift rearward. This geometry caused the skid to wear more rapidly at the rear than at the front. Figure 10 shows a photograph of the skid specimens after testing, and the wear is evident on the rear and front of the skids.

Data from a typical test run are presented in figure 11. A fairing of the drag load gives an average drag load of approximately 8800 lb. The actual vertical load is indicated to be 43 000 lb after the previously mentioned calibration was applied to the measured data.

Some tests resulted in two average levels of vertical load during the test, as can be seen in figure 12. The existence of two relatively distinct levels was due to the hydraulic system onboard the test carriage which sometimes lowered the drop carriage containing the skid apparatus faster than the hydraulic load system could apply load on top of the drop carriage. After a short period of time, the desired hydraulic vertical load would then be applied, thus raising the skid specimen vertical load from the dead weight of the drop carriage to the desired total vertical load. Two levels of vertical load are reported in table 1 for about half the test runs.

Very little damage to the runway occurred during the skid tests, and consequently all the skids were tested in the same path. A photograph of minor runway surface damage in the path is shown in figure 9. The damage shown occurred at the spot of initial touchdown, and the rest of the slideout skid path was not damaged significantly.

The Inconel 718 skid was tested at approximately 160 knots. As can be seen in table 1, the vertical load for the three tests varied from 30 000 to 62 000 lb which resulted in bearing pressures, for at least portions of the tests, of 460 to 910 psi and in drag-force friction coefficients of 0.15 to 0.20. No obvious correlation was seen between bearing pressure of the skids and friction coefficient. If one were using skids to provide the braking for an aircraft landing at 200 knots, a nominal slide distance might be 6000 ft. The average wear for an equivalent 6000 ft of slide distance (based on wear for skid distances from 220 ft to 308 ft) would have been approximately 6 to 7.75 in. This amount of wear would seem to rule out the use of Inconel 718 for use on a high-speed landing of the Shuttle orbiter on a concrete runway.

The skids made of 4340 steel were tested at 16, 100, and 160 knots. For speeds higher than 16 knots, the drag-force friction coefficient was 0.17 to 0.21. For the slow-speed test (16 knots), the drag-force friction coefficient was 0.40. The average wear for an equivalent 6000 ft of slide distance based on actual slide distances of 204 to 330 ft range from 5.35 to 6.65 in. Skidding on this material produced a large amount of hot sparks and molten material, as can be seen in figure 13. For run 6 in table 1, no wear data are reported for the slow-speed test because the slide distance was very short. Extrapolation of meaningful wear values for an equivalent 6000-ft slide was not possible.

The Stellite-coated skid at a bearing pressure of 500 to 600 psi produced a friction coefficient of 0.12 to 0.15 for the first test of the three tests with this skid. The depth of Stellite on the Inconel 718 base material was not known with certainty for this skid, and thus the first test was probably the only one that had Stellite over the entire bottom surface of the skid. The other two tests with this skid resulted in sliding

on a surface that had one area of Stellite and another area of Inconel 718, with the percentage of each material unknown. The friction coefficient for the last two runs ranged from 0.13 to 0.20. The average wear for an equivalent 6000 ft of slide distance based on the actual 210-ft slide distance (run 8) was 3.35 in. The remaining two runs had wear rates of 5 to 6.7 in. of wear for an equivalent 6000 ft of slide distance, which was more like the wear rate for the Inconel 718 skid discussed previously.

The tungsten skid with medium carbide chips was tested at speeds of 95 to 171 knots and at bearing pressures of 510 to 1110 psi. The friction coefficient for this skid ranged from 0.09 to 0.12. The wear for an equivalent 6000 ft of slide distance ranged from 0.53 to 1.33 in., based on the wear due to an actual slide distance of 340 to 440 ft for three runs.

The tungsten skid with coarse carbide chips was tested at approximately 170 knots and at bearing pressures of 200 to 680 psi. The friction coefficient for this skid was 0.12 to 0.15 and the wear for an equivalent slide distance of 6000 ft was 0.43 to 2.30 in.

The last skid material tested was 1020 steel, and it was tested twice for approximately 400 ft at speeds of 158 and 173 knots. The bearing pressures for this skid were 360 to 1030 psi and produced friction values of 0.15 to 0.23. The wear rate for the 1020 steel was relatively high at 4.85 to 7.90 in. for an equivalent 6000 ft of slide distance.

Figure 14 shows a bar graph of the friction coefficients for the various skid materials tested. Only data for bearing pressures of 510 to 680 psi at speeds of approximately 157 to 171 knots are presented in the figure for comparison. If data values come from more than one run, the values are averaged to get the value for the bar graph. The highest friction for these speeds and bearing pressures was 0.21 from the 4340 steel skid, and the lowest friction was 0.11 from the tungsten skid with medium carbide chips.

For the various skid materials, figure 15 shows the average wear depth for a slide of 6000 ft and also per foot of slide. The data shown are for speeds of 150 to 170 knots, and all bearing pressures (200 to 1110 psi) were used because although different portions of a test were frequently at different bearing pressures, wear could be determined only at the end of the test. All applicable data for a given skid material were averaged to obtain the value shown. The tungsten/carbide skids exhibited the lowest wear rate and the Inconel 718 skid exhibited the highest wear rate. Thus, a skid made of tungsten with embedded carbide chips would likely be considered the most promising choice for an aircraft landing-gear skid or overload protection skid because of its small thickness requirement and its acceptable sliding friction coefficient.

Concluding Remarks

Skids constructed of six different metals were tested to determine their drag-force friction coefficients and wear rates for sliding on a rough, grooved concrete runway. The skids were tested at speeds up to 170 knots and at bearing pressures up to 1110 psi. No obvious correlation was found between bearing pressures of the skids and the friction coefficients that they developed in the range tested. The skids constructed of tungsten with embedded carbide chips exhibited the lowest wear, with a wear rate of 0.93 to 1.37 in. for an equivalent 6000 ft of slide distance. The coefficient of sliding friction for this material was approximately 0.12. For comparison, an Inconel 718 skid exhibited a wear rate of 7.1 in. for an equivalent 6000 ft of slide distance and developed a friction coefficient of 0.17. Therefore, skids constructed of tungsten with embedded carbide chips are considered to be a likely candidate for an aircraft landing-gear skid or overload protection skid because of the low wear and friction behavior of this material.

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December 16, 1993

References

1. Wilson, Ronald J.: *Drag and Wear Characteristics of Various Skid Materials on Dissimilar Lakebed Surfaces During the Slideout of the X-15 Airplane.* NASA TN D-3331, 1966.

2. Dreher, Robert C.; and Batterson, Sidney A.: *Coefficients of Friction and Wear Characteristics for Skids Made of Various Metals on Concrete, Asphalt, and Lakebed Surfaces.* NASA TN D-999, 1962.

3. Daugherty, Robert H.; and Stubbs, Sandy M.: *Orbiter Post-Tire Failure and Skid Testing Results.* SAE Paper 892338, 1989.

4. Davis, Pamela A.; Stubbs, Sandy M.; and Tanner, John A.: *Langley Aircraft Landing Dynamics Facility.* NASA RP-1189, 1987.

Table 1. High-Pressure Skid Test Data

(a) Friction data

Run	Speed at touchdown, knots	Average vertical load, lb	Bearing pressure, psi	Average drag force, lb	Friction coefficient
Inconel 718					
1	156	39 000	560	7 900	0.20
2	163	48 000 30 000	740 460	7 000 5 000	0.15 0.17
3	158	40 000 62 000	550 910	6 100 9 700	0.15 0.16
4340 steel					
4	157	43 000	630	8 800	0.21
5	154	33 000 51 000	320 840	6 400 8 700	0.19 0.17
6	16	65 000	750	26 000	0.40
7	100	40 000	600	8 000	0.20
Stellite					
8	169	33 000 41 000	520 600	5 000	0.15 0.12
[a]9	162	38 000 60 000	580 910	7 700	0.20 0.13
[a]10	84	42 000	620	6 900	0.16
Tungsten/medium carbide					
11	165	38 000	600	3 400	0.09
12	95	43 000	680	5 000	0.12
13	171	34 000 65 000	510 1110	3 300 7 500	0.10 0.12
Tungsten/coarse carbide					
14	171	13 000 44 000	200 670	1 900 6 200	0.15 0.14
15	167	65 000	680	8 000	0.12
1020 steel					
16	173	42 600	1030	6 500	0.15
17	158	34 000 44 000	360 1030	7 800 9 100	0.23 0.21

(b) Wear data

Run	Slide distance, ft	Wear on skid, in.		Wear rate, in/ft		Wear for 6000-ft skid distance, in.		Average wear for 6000-ft distance, in.
		Front	Rear	Front	Rear	Front	Rear	
Inconel 718								
1	290	0.235	0.5	0.00079	0.0017	4.8	10.3	7.55
2	220	0.045	0.4	0.0002	0.0018	1.2	10.9	6.05
3	308	0.175	0.62	0.00057	0.002	3.4	12.1	7.75
4340 steel								
4	204	0.11	0.325	0.00054	0.0016	3.2	9.6	6.04
5	214	0.045	0.335	0.00021	0.0016	1.3	9.4	5.35
6	20	(b)	(b)	(b)	(b)	(b)	(b)	(b)
7	330	0.21	0.52	0.00064	0.0016	3.8	9.5	6.65
Stellite								
8	210	0.095	0.14	0.00045	0.00067	2.7	4.0	3.35
[a]9	340	0.3	0.46	0.00135	0.00088	5.3	8.1	6.70
[a]10	340	0.175	0.395	0.00052	0.0012	3.1	7.0	5.05
Tungsten/medium carbide								
11	340	0.025	0.035	0.000074	0.0001	0.44	0.62	0.53
12	440	0.03	0.1	0.000068	0.00023	0.41	1.36	0.89
13	440	0.06	0.135	0.00014	0.00031	0.82	1.84	1.33
Tungsten/coarse carbide								
14	417	0.025	0.035	0.00006	0.00008	0.36	0.5	0.43
15	450	0.15	0.195	0.00033	0.00043	2.0	2.6	2.30
1020 steel								
16	400	0.23	0.42	0.00058	0.00105	3.4	6.3	4.85
17	390	0.335	0.69	0.00086	0.00177	5.2	10.6	7.90

[a]Some of the Stellite was worn through with the result that some of the sliding surface was on the Inconel 718 base material.
[b]Wear was not measured/calculated because of short slide distance.

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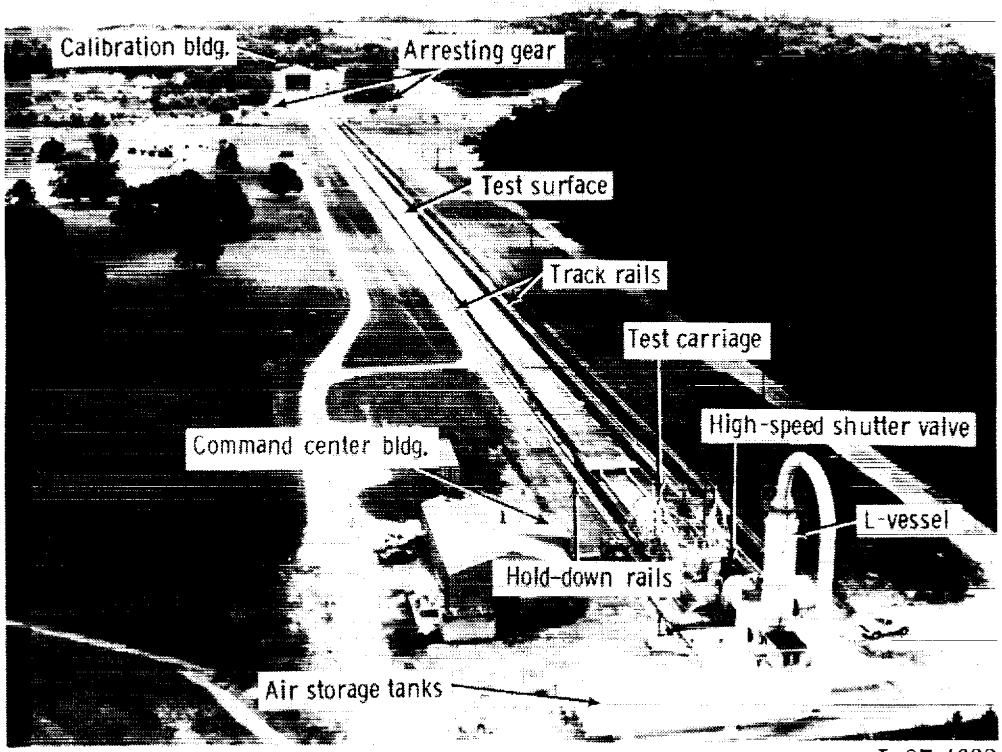

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Figure 1. The Langley Aircraft Landing Dynamics Facility.

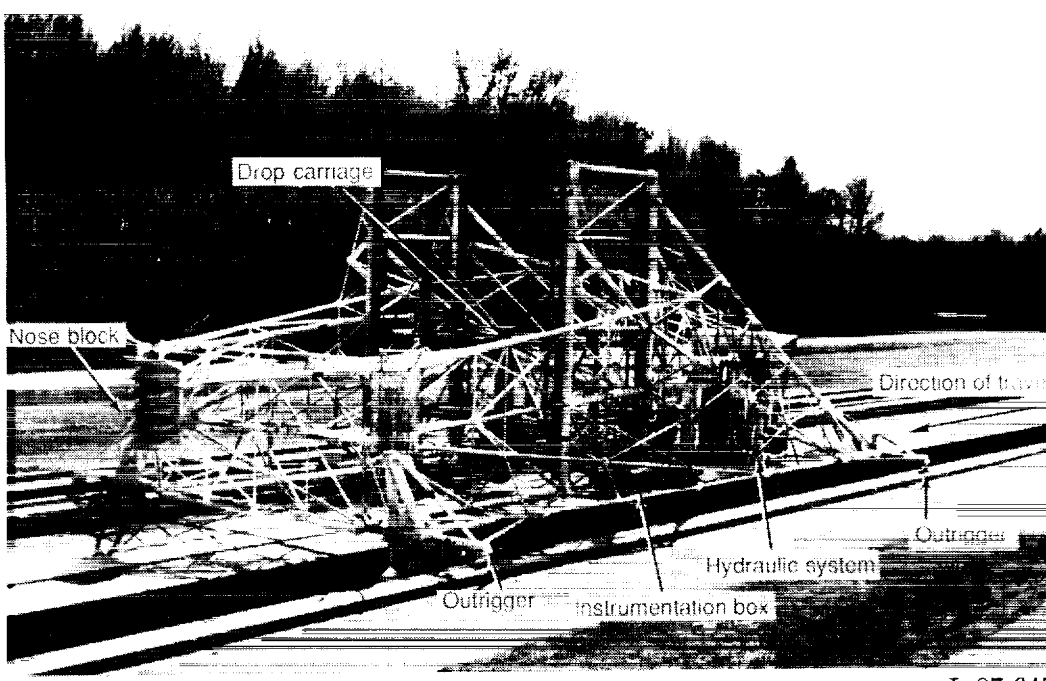

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Figure 2. High-speed carriage.

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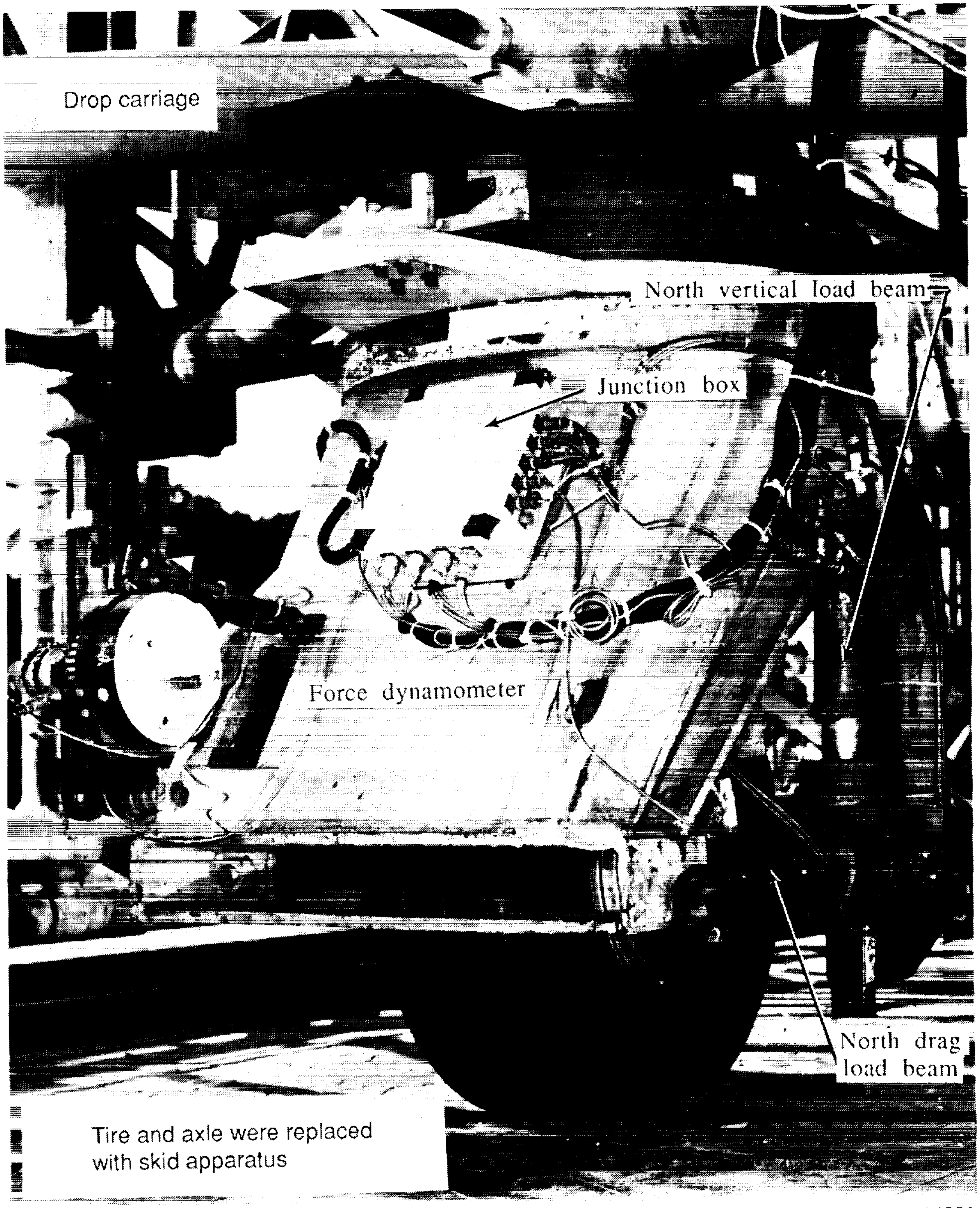

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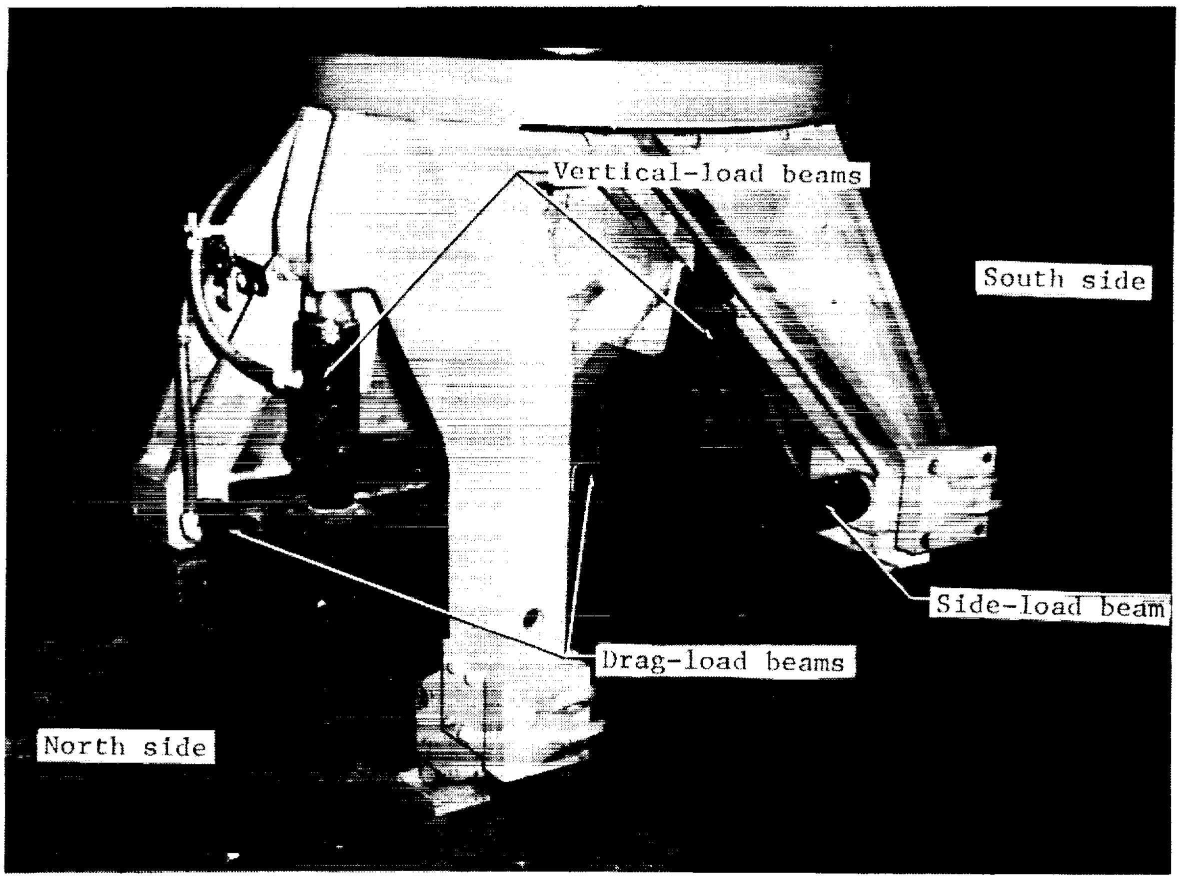
Figure 3. Conventional setup of force-measurement dynamometer.



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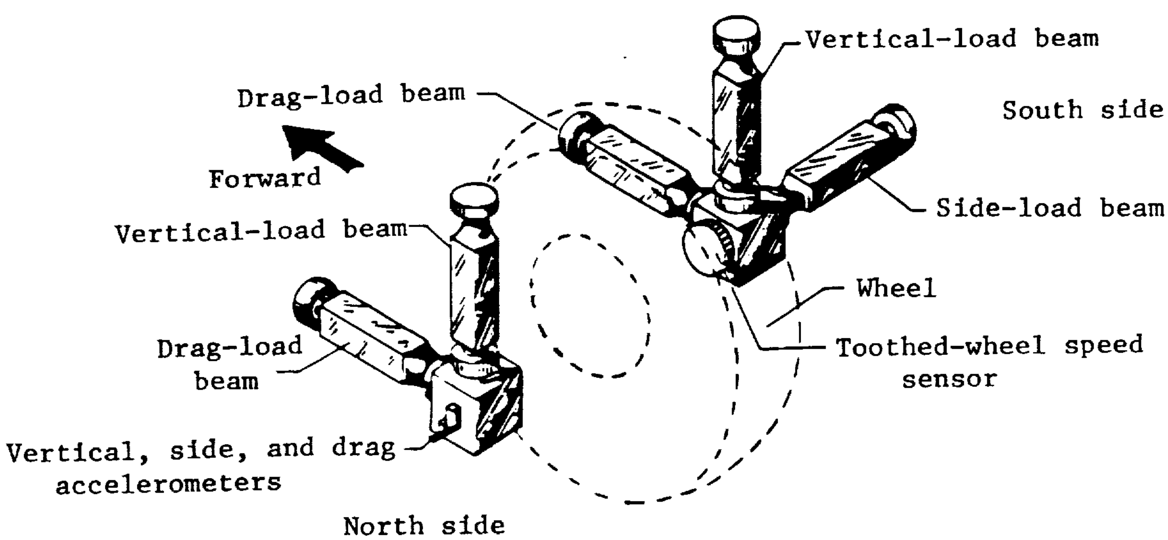

Figure 4. Force-measurement system.

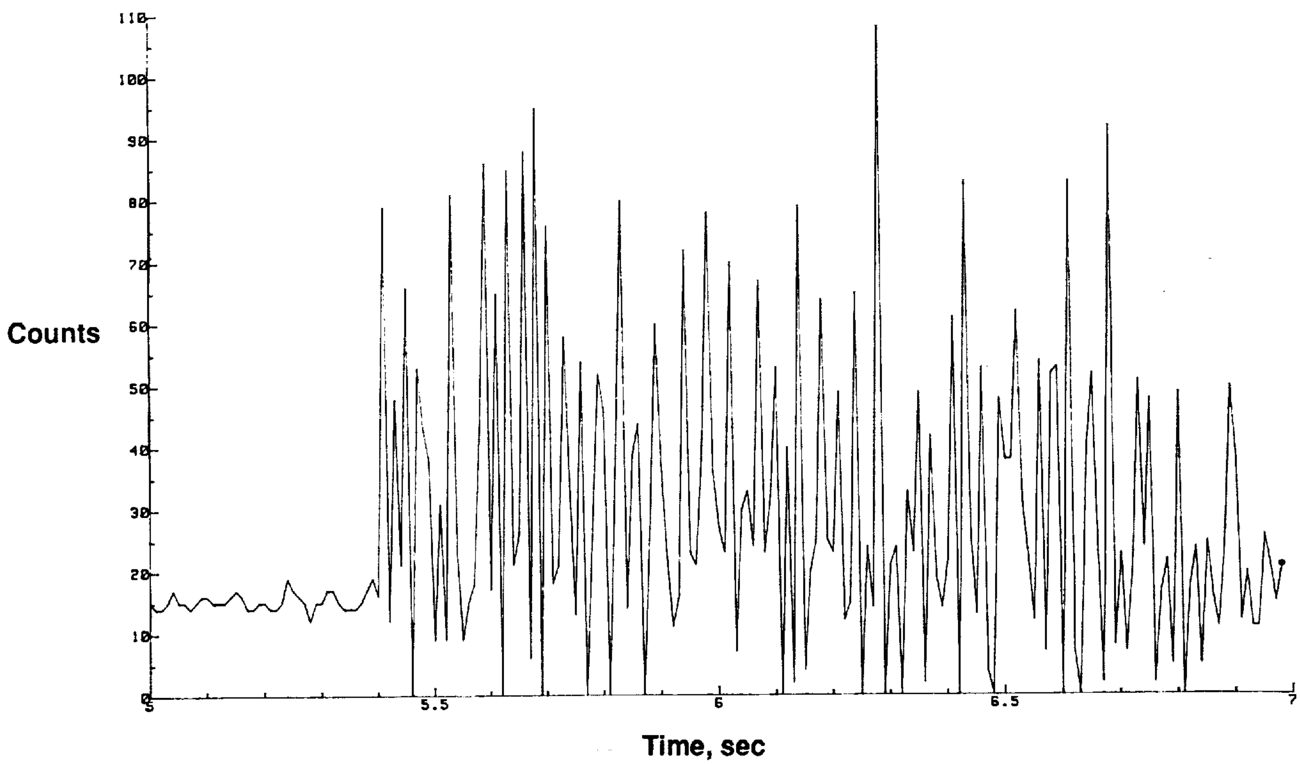

Figure 5. Typical over-scale values on one of two drag-load beams.

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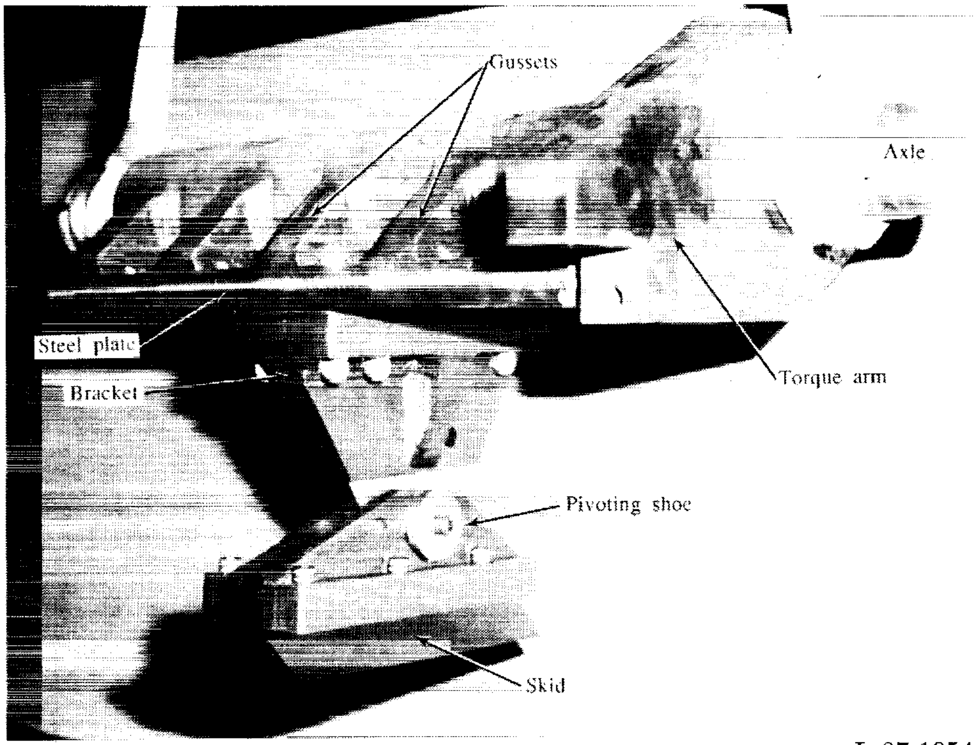

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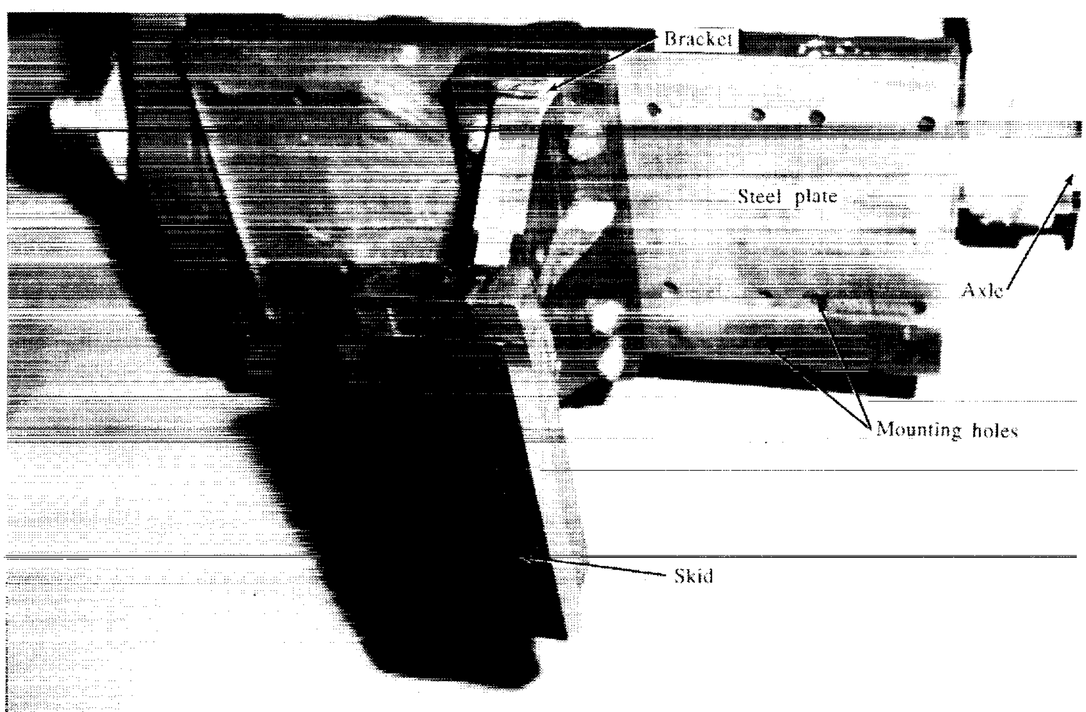
(a) Three-quarter view.



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(b) Bottom view.

Figure 6. Skid test apparatus.

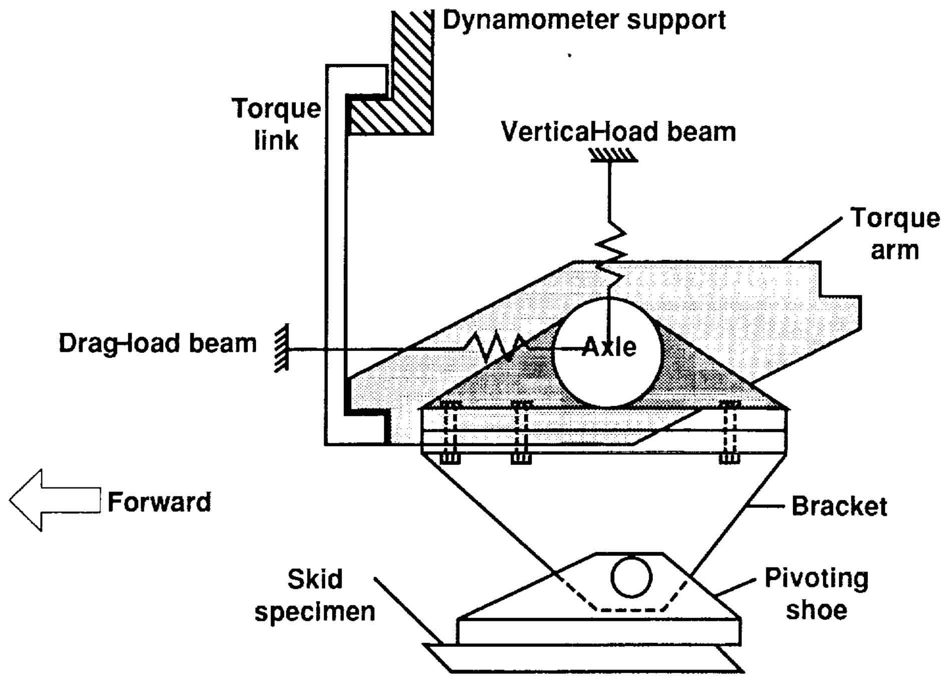

Figure 7. Sketch of torque reaction apparatus.

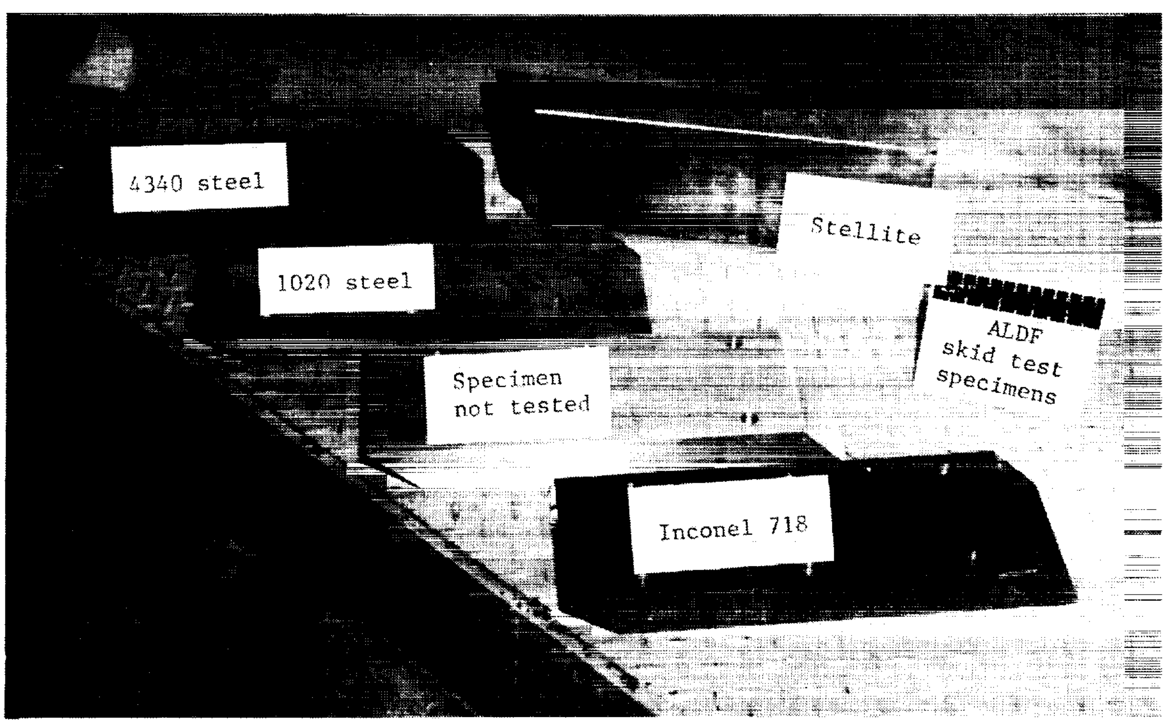

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Figure 8. Several skid specimens before testing.

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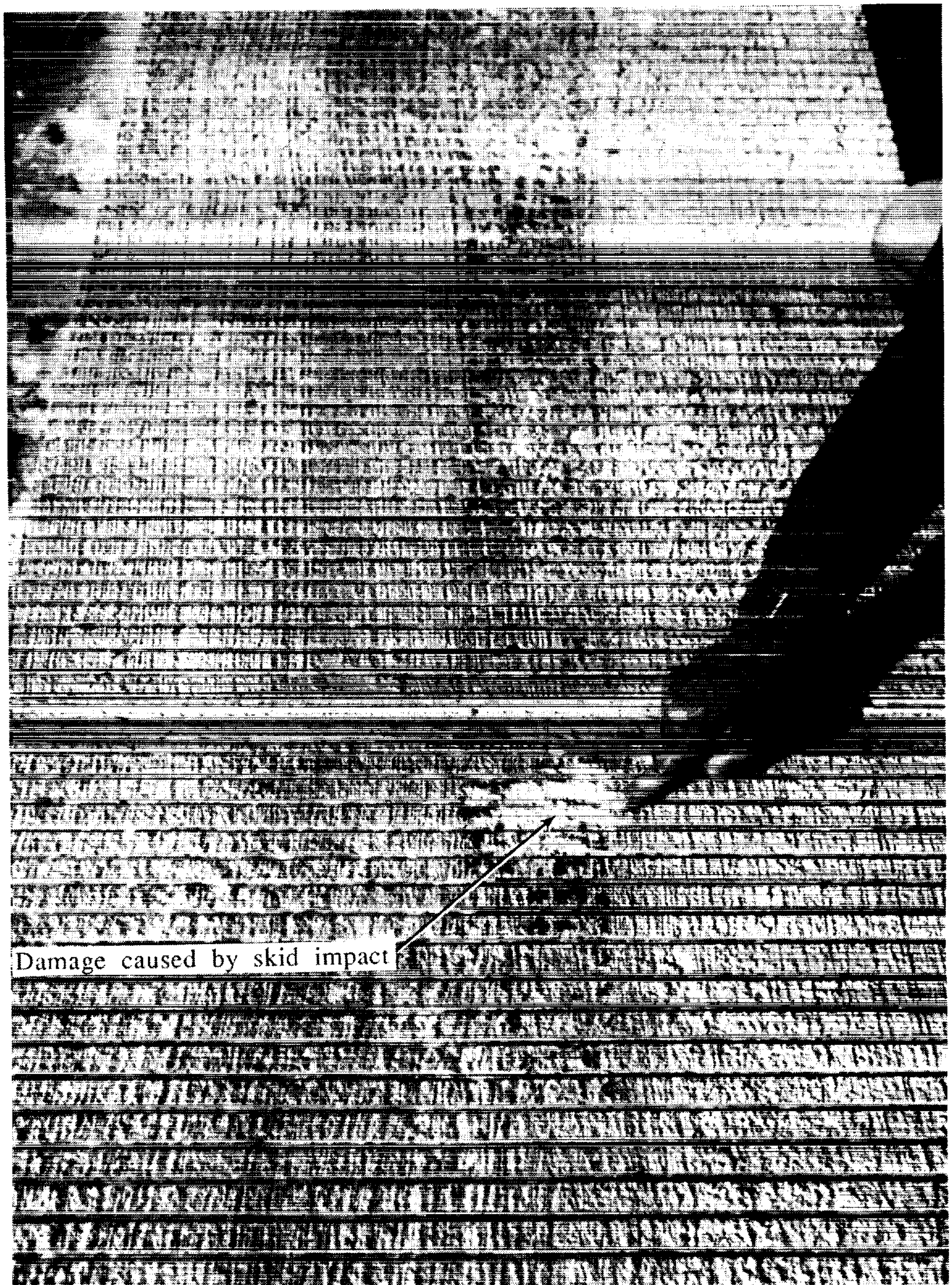

Figure 9. Simulation of rough, grooved concrete runway at the Kennedy Space Center.

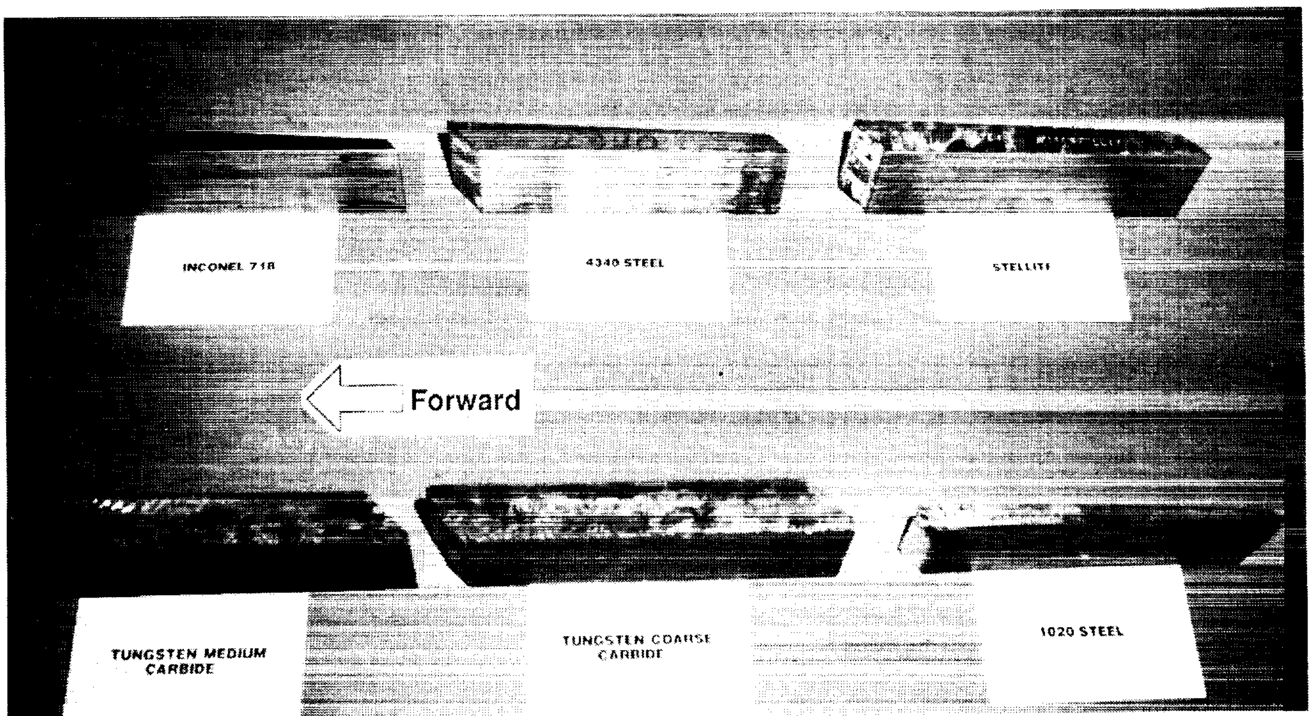

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Figure 10. Skid specimens after testing.

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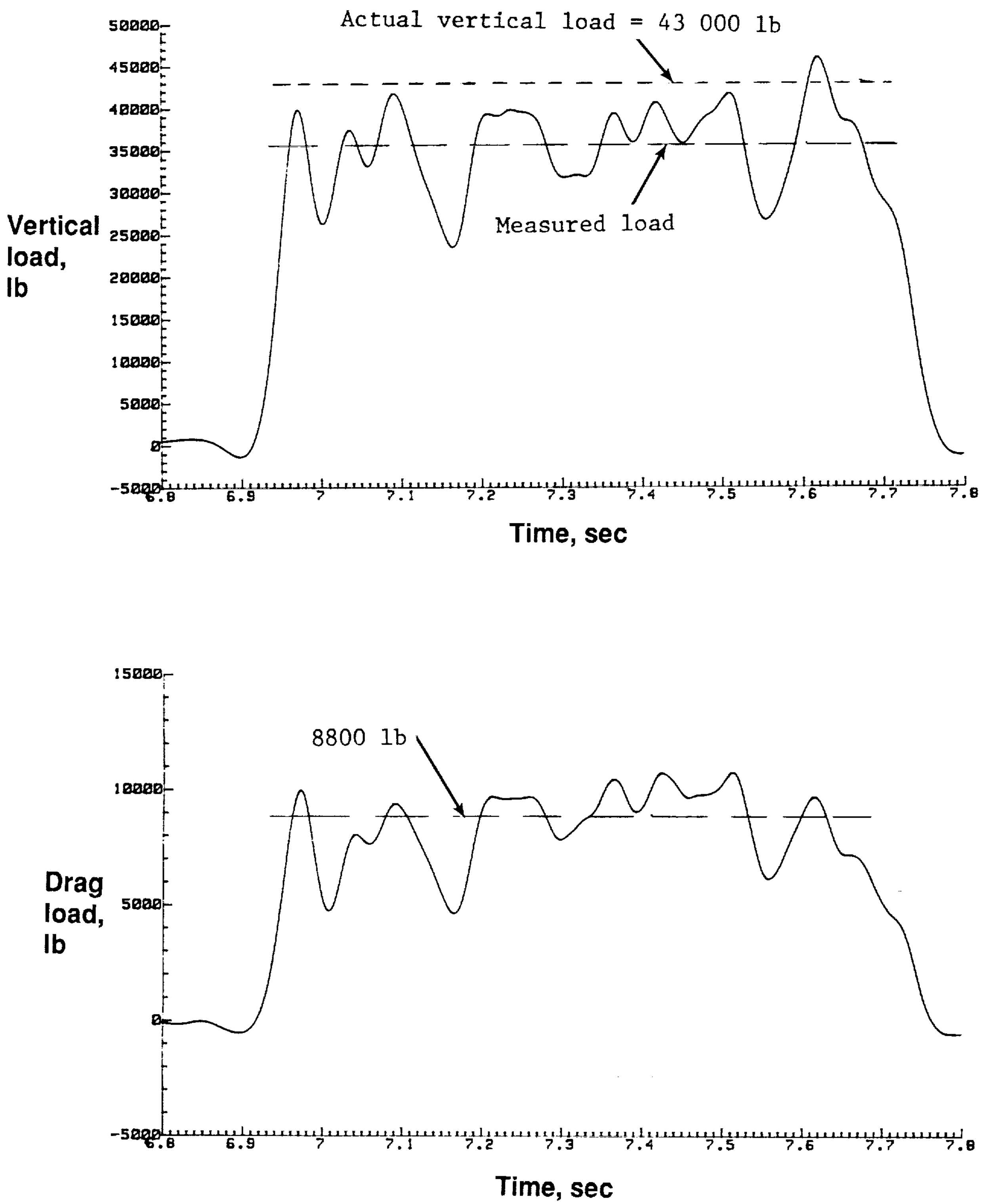

Figure 11. Time histories for typical test run.

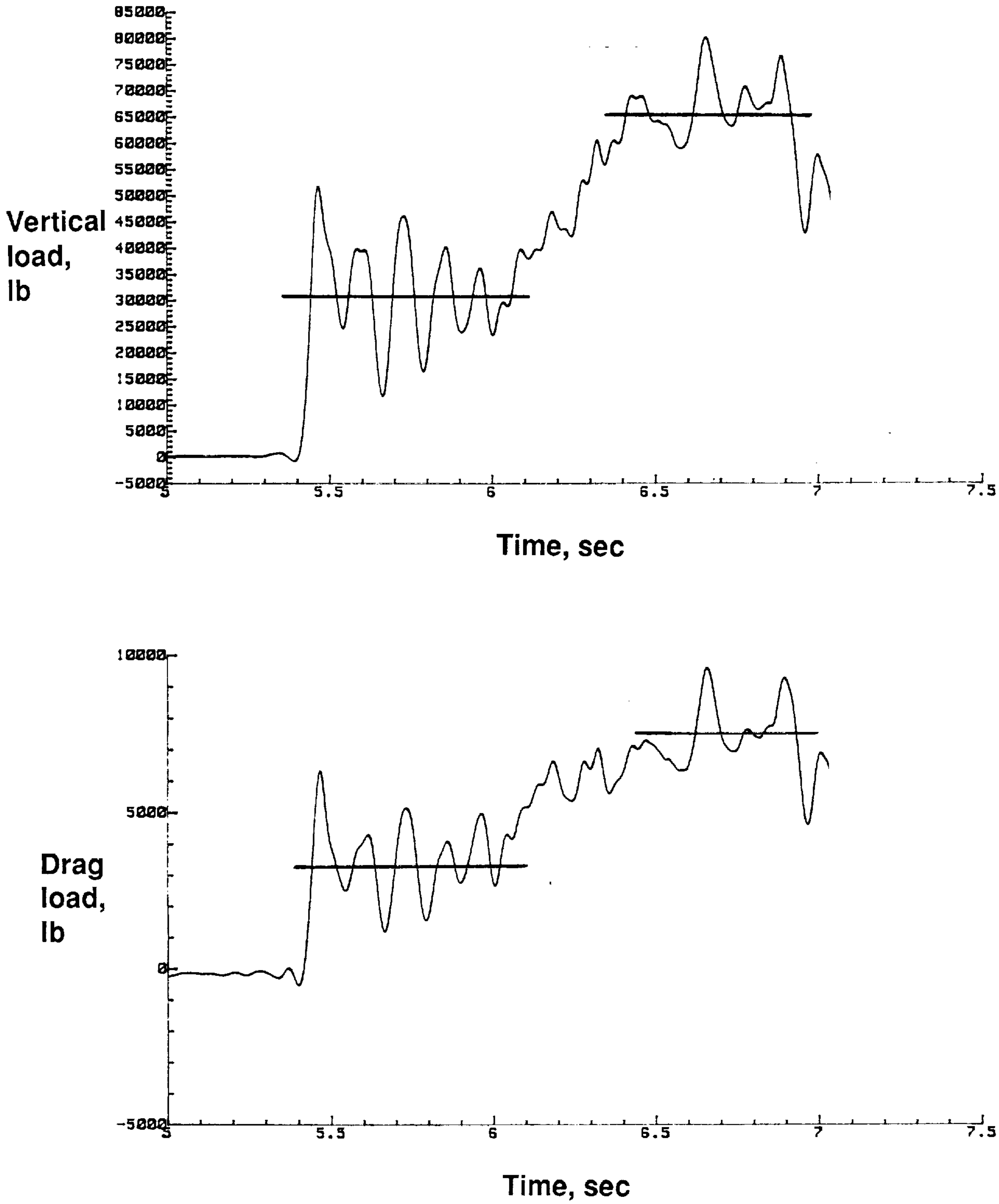

Figure 12. Typical time history of test that resulted in two different vertical-load levels.

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Figure 13. Fire produced by skidding on a 4340 steel skid specimen.

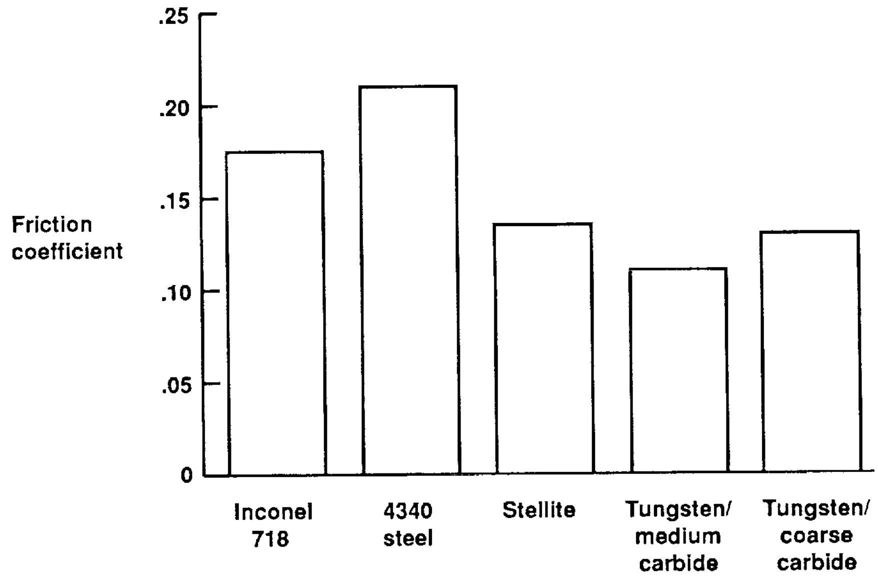

Figure 14. Comparison of friction performance of various skid materials at speeds of 157 to 171 knots and at bearing pressures of 510 to 680 psi.

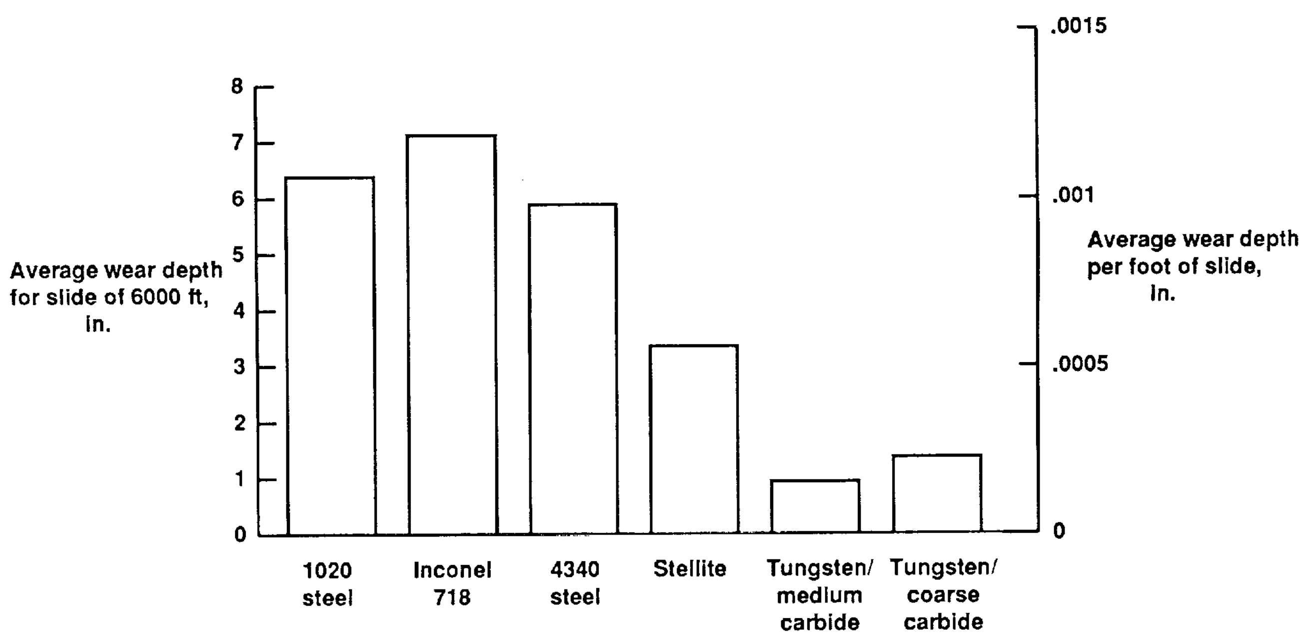

Figure 15. Comparison of various skid materials' wear performance at speeds of 150 to 170 knots and at bearing pressures of 200 to 1110 psi.

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13. ABSTRACT *(Maximum 200 words)*

Skids have been used at various times for aircraft landing gear ever since the Wright Flyer appeared in the early 1900's. Typically, skids have been employed as aircraft landing gear either at low speeds or at low-bearing pressures. In this investigation, tests were conducted to examine the friction and wear characteristics of various metals sliding on a rough, grooved concrete runway. The metals represented potential materials for an overload protection skid for the Space Shuttle orbiter. This report presents data from tests of six skid specimens conducted at higher speeds and bearing pressures than those of previous tests in the open literature. Skids constructed of tungsten with embedded carbide chips exhibited the lowest wear, whereas a skid constructed of Inconel 718 exhibited high wear rates. Friction coefficients for all the skid specimens were moderate and would provide adequate stopping performance on a long runway. Because of its low wear rate, a skid constructed of tungsten with embedded carbide chips is considered to be a likely candidate for an aircraft skid or overload protection skid.

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